CHAPTER 4

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
HETEROTROPHIC BIOLOGICAL DENITRIFICATION FOR REMOVAL OF NITRATE

Prepared By:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLES

1.0 INTRODUCTION

1.1 Application of This Test Plan

This document is the ETV Testing Plan for the Biological Denitrification Process for the Removal of Nitrates from Contaminated Water. This Testing Plan is to be used as a guide in the development of Product-Specific Test Plan (PSTP) procedures for testing biological denitrification (BD) treatment equipment, within the structure provided by the EPA/NSF Environmental Technology Verification (ETV) Protocol Document for nitrate removal. Refer to the "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies" as well as the Test Plans for Equipment Verification Testing Plan for Reverse Osmosis and Nanofiltration Processes for further information.

This document is applicable only to heterotrophic carbon-based fixed-film denitrification systems and not to suspended-growth systems. This document is not applicable to autotrophic denitrification systems including hydrogen and sulfur-based processes.

Post-denitrification treatment systems for the removal of residual soluble and suspended carbonaceous materials may be required to bring the biologically denitrified water to drinking water standards. Such equipment is considered to be a separate treatment module whose performance and operation are outside the scope of this document. Where such post-treatment is required to reduce the fouling potential of the BD throughput as measured by turbidity, suspended solids, and residual Total Organic Carbon (TOC), the reader should consult other NSF publications related to residual contaminant removal including the ETV document *Protocol for Physical Removal of Microbiological and Particulate Contaminants, and Test Plans for Membrane Filtration, Coagulation and Filtration, Bag and Cartridge Filters, and Precoat Filtration*. These documents should be useful in determining post-denitrification treatment needs.

In order to participate in the equipment verification process for BD processes, the Equipment Manufacturer shall retain a Field Testing Organization (FTO) that is NSF-qualified to employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the PSTP. The procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modifications made for adaptations to specific equipment. A recommended format of the procedures written for each Task should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

1.2 Objectives of Verification Testing

Testing of equipment covered by this Verification Testing Plan shall be conducted by an NSF-qualified FTO. Water quality analytical work to be carried out as a part of this Verification Testing Plan shall be contracted with a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA. The FTO shall provide full details of the procedures to be followed for each task in the PSTP. The FTO shall specify the operational conditions to be evaluated during the Verification Testing.

The Manufacturer shall define the verification testing objective(s). These specific objectives of the equipment verification testing should be different for each Manufacturer, depending upon the statement of objectives of the specific equipment to be tested. The testing objectives developed by each Manufacturer shall be defined and described in detail in the PSTP developed for each piece of equipment. The objectives of the equipment verification testing may include:

- Verifying the performance of the equipment by generating field data in support of meeting a specific contaminant level in the treated water;
- Evaluating new advances in equipment and equipment design;
- Verifying the performance of the equipment used in a specific environment such as a coastal region where ocean disposal is available;
- Verifying the performance of the equipment operating within a specific range of untreated water quality;
- Verifying the performance of the equipment used for specific modes of operation such as continuous or interrupted operation.

Multiple testing objectives may be included in the PSTP. An important aspect in the development of the verification testing is to describe the procedures that will be used to verify the statement of performance objectives made for water treatment equipment. A verification testing plan document incorporates the Quality Assurance/Quality Control (QA/QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Verification testing conducted at a single site may not represent every environmental situation which may be acceptable for the equipment tested, but it should provide data of sufficient quality to make a judgment about the application of the equipment under conditions similar to those encountered in the verification testing.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF and/or accepted by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

1.3 Scope of the PSTP

Specifically, the PSTP shall include at least the following items:

- Roles and responsibilities of verification testing participants;
- A brief statement of the objectives of the test plan;
- A brief statement of the water quality treatment objectives;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation;
- Experimental design of the Field Operations Procedures;
- Quality assurance and quality control (QA/QC) procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing;
- Health and safety measures relating to biohazard (if present), chemical, electrical, mechanical and other safety codes.

2.0 BACKGROUND

Heterotrophic biological denitrification is a well-established process in the realm of wastewater treatment. However, this process has not been used on a full-scale basis in the field of water treatment in the U.S., but there are several full-scale plants being operated in Europe (Dahab et al., 1998; Gayle, et al., 1989). The primary reason behind the slow transfer of technology from the wastewater treatment to potable water treatment is the obvious concern over potential contamination of the treated water by bacteria and residual organics from the bio-denitrification process. This is a legitimate concern that must be kept in mind when designing such treatment processes for water treatment.

Numerous studies (Dahab and Woodbury, 1998 and Dahab and Kalagiri, 1996) reported on the potential for using biological denitrification for nitrate reduction in groundwater supplies in laboratory-scale experiments. The results indicated that fixed-film denitrification can be expected to reduce the nitrate concentration in the influent water supply from as high as 100 mg/L (as N) to levels within the 1.0 mg/L (as N) range. These removals translate into an efficiency of nearly 100 percent, which is generally not matched by other processes available for nitrate reduction. However, some residual soluble as well as insoluble organic matter should be expected in the denitrified water supply. Further treatment can reduce these solids to levels sufficient to meet prevailing drinking water standards.

In heterotrophic biological denitrification, facultative microorganisms are contacted with the water supply containing nitrates and an added carbon source in an anoxic (oxygen-free) environment. Under these conditions, the bacteria utilize nitrates as a terminal electron acceptor in lieu of molecular oxygen. In the process, nitrates are reduced to nitrogen gas, which is harmless and can be directly discharged to the atmosphere. The extraneous carbon source is necessary since it supplies the energy required by the microorganisms for respiration and synthesis while serving as an electron donor. Most denitrification studies have used methanol (CH_3OH) as the carbon source. If a simple carbon source is chosen such as ethanol or acetic acid, then the biomass produced during the process should be correspondingly low; a useful characteristic in that the overall excess biomass production is minimized.

Since heterotrophic denitrifying bacteria require an organic carbon source for their respiration and growth, a wide variety of organic compounds have been used. These organics include methanol, ethanol, acetic acid, glucose, and other more complex organics. While the types of organic compounds may affect the biomass yield, the choice is generally based on economic comparison. The availability of ethyl alcohol from agricultural sources could make this carbon source a strong candidate for denitrification systems. It should be noted that methanol toxicity is such that it is not recommended as electron donor and carbon source for drinking water denitrification.

Another important factor is the presence of dissolved oxygen in the waters and its inhibiting effects. To effect denitrification, the oxygen concentration must be reduced to a level low enough to avoid inhibition or repression of nitrate reductase. Unless dissolved oxygen is removed by chemical addition, the amount of electron donor (organic carbon) added must be equal to that needed to remove the oxygen as well as the nitrate.

Biological denitrification can be carried out in suspended or attached growth systems. In suspended growth systems, the bacterial culture is "suspended" within the contents of the reactor vessel by constant mixing or agitation. In these systems, sedimentation is required to settle out the bacterial biomass so it can be returned to the reactor vessel, or otherwise removed by wasting. Such systems are common in wastewater treatment

applications. The principal advantages of suspended growth systems include the ability constantly return biomass into the system and small tankage requirements. However, suspended growth systems are subject to damage or washout by hydraulic transients and influent shock loads. They are generally not suited for handling periods of extended shutdown.

In fixed-film (also known as biofilm) systems, the bacterial biomass is physically attached to a solid matrix, which serves to support the bacterial mass by providing surface area on which the bacteria can grow in a film-like layer. Attached growth systems can be of the static media type or the expanded-bed (i.e. fluidized) type. In static media systems, the solid matrix typically is made up of synthetic modules that are stacked in some fashion (or simply dumped, depending on their size and configuration) in the reactor vessel. These media can have high porosity, light weight (when synthetic materials are used) and high specific surface area (i.e. surface area per unit volume of medium). Static media attached growth systems are operated in either downflow or upflow regimes although upflow systems are more common due to the reduced chance of plugging associated with their operation and the fact that the bacterial biomass is constantly submerged.

Fluidized-bed systems are operated in an upflow manner so that the bacterial growth matrix bed is expanded hydraulically as the water is pumped from the bottom to the top of the reactor. In expanded-bed systems, the support media are generally of the granular type (both natural and synthetic) to facilitate expansion of the bed. As the bed is expanded the entire surface of the granular material is made available for bacterial support. Because of this fact, expanded-bed systems have been reported to be loaded at rates exceeding static-bed systems. However, the additional costs associated with pumping to maintain bed expansion or fluidization must also be considered during design evaluation. With no known exceptions, all full-scale biological denitrification systems designed for potable water treatment have been of the static-bed fixed film type.

3.0 OVERVIEW OF TASKS

This ETV Testing Plan is divided into 6 tasks. A brief overview of the tasks to be included in the verification testing program is presented below:

3.1 Task 1: Characterization of Feed Water

A full characterization of the source water must be made prior to initiating operation so that the potential for fouling and mineral precipitation (scaling) and other possible interferences can be defined and/or predicted. Results of this analysis shall be used to define feed water pretreatment requirements, chemical doses and system operating conditions, and to identify potential foulants in the source water for monitoring during operation.

3.2 Task 2: BD Start-up and Initial Performance

The objective of this task is to evaluate BD start-up and subsequent steady-state operation. Start-up conditions including the need for bacterial seed (inoculum) must be characterized. Furthermore, the usability of the biological denitrification process and potential fouling (including excess biomass and potential hydrogen sulfide production) shall be evaluated in relation to feed water quality.

3.3 Task 3: Product and Residual Management

The objective of this task is to evaluate the quality of water produced by the BD system, referred to as product water or BD effluent. Multiple water quality parameters shall be monitored during each operational period. A basic goal of this Task is to confirm that BD-treated waters meet the manufacturer's performance objectives for nitrite. BD effluent quality shall be evaluated in relation to feed water quality and operational conditions to determine if additional treatment is required. Any wastewater or sludge streams shall also be characterized and management plans for the proper disposal of BD residual biosolids are to be identified.

3.4 Task 4: Process and Equipment Maintenance

An important aspect of BD operation is the maintenance of the system so that an adequate inventory of biological (bacterial) mass (i.e. biomass) is maintained while avoiding excess biomass conditions that may lead to impaired effluent quality or to system support matrix clogging. Another intent of this task is to provide procedures and methods for insuring the continued integrity and operability of all equipment and associated appurtenances.

3.5 Task 5: Data Reduction and Presentation

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF for data obtained during the Verification Testing.

3.6 Task 6: Quality Assurance/Quality Control

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during Verification Testing.

4.0 TESTING PERIODS

On the assumption that the source water is a groundwater, which normally exhibits minor or no significant changes in seasonal water quality, the required operational tasks in the Verification Testing Plan (Tasks 1-4) shall be performed at least once during a 1-year period, not including mobilization, start-up, and Initial Operations.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary if feed water quality is known to be seasonally variable. If one verification testing period is selected, the feed water should represent the worst-case concentrations of nitrate concentration, which can verify the manufacturer's objectives. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions. Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined through feed water characterization. Verification test periods shall last a minimum of 3000-hours. The purposes of the 3000-hour test period are: 1) to provide a data base for a long period of time to demonstrate start-up (establishment of biomass in system) and

steady-state conditions; 2) to assess the system recovery after short periods of shutdown; and 3) to provide opportunity for the treatment of feed water having variable quality.

5.0 DEFINITIONS

5.1 Biological Denitrification: a bacteria-mediated (i.e. biological) process in which nitrate is reduced into nitrogen gas by denitrifying bacteria (typically facultative heterotrophes) under anoxic (oxygen-free) conditions. The process requires that an electron donor (typically an organic carbon source) be present for the reaction to go to completion.

5.2 BD Effluent: Product water produced by the biological denitrification (BD) treatment system.

5.3 Denitrified Effluent: The same as BD Effluent.

5.4 System Feed Water: Source water introduced into the BD process for treatment.

5.5 Reactor Feed Water: Influent feed water introduced into the BD reactor system, consisting of raw system feed water, and in rare occasions, a combination of raw system feed water and recycled reactor effluent being returned for further treatment.

5.6 Fouling: A condition in which the BD effluent quality is impaired by the presence of excess biological solids being discharged by the BD reactor or fouling resulting from extraneous reactions including sulfate reduction to produce traces of hydrogen sulfide. Fouling in this case also is referred to as "biofouling". Fouling could also be the result of other contaminants that might be present in the feed water.

5.7 Carbon Source: The material to be used as a source of elemental carbon for heterotrophic bacterial denitrification to proceed. The organic carbon serves as an electron donor in the heterotrophic biological denitrification reaction as well as a source of energy for bacterial metabolism. This carbon source can be one (or a combination of) several organic substances including alcohols (such as methyl alcohol or ethyl alcohol), organic acids (such as acetic acid) or other similar organic substances including sugars.

5.8 Electron Donor/Electron Acceptor: The term electron donor generally refers to the organic carbon source to be used in the heterotrophic denitrification process whereas the electron acceptor refers to substances being reduced in the denitrification process, principally nitrate, but it also may include sulfate, if present in the raw feed water being denitrified.

5.9 Bacterial Seed (Inoculum): This term refers to the bacteria that must be added to the denitrification reactor to accomplish the conversion of nitrate biologically into nitrogen gas. Such bacteria must be inoculated into the reactor system for immobilization on the reactor bacterial support matrix. Bacterial inoculums can be of a pure culture or a mixed culture variety.

5.10 Reactor: The term reactor refers to the vessel in which the denitrification process is to be accomplished. The combination of the reactor vessel, bacterial support matrix and other related appurtenances are referred to as the "Reactor System."

5.11 Start up: The period of time following the installation of the reactor system, addition of bacterial seed and the commencing of operation. During this period, the product water may contain excess biomass

and excessive nitrate concentrations indicating that the treatment process has not stabilized yet. Generally, start-up should be in the order of 3 to 5 weeks.

5.12 Steady-State Operation: Steady-State Operation begins after the reactor system had gone through a successful start-up with nitrate concentrations in the reactor effluent approaching the targeted concentrations and with minimal occurrence of fouling.

5.13 Biofilm: Biofilm is the structural appearance of bacterial mass (biomass) on the surface of the reactor support matrix. Ideally, the biofilm should be a consistent and uniform accumulation of bacterial solids that appear like a gelatinous and slime-like layer that can be put into contact with the water being treated for the removal of nitrate contamination.

5.14 Support Matrix: The porous material to be used as reactor column packing to support the growth and accumulation of denitrifying bacteria. These materials typically consist of small individual packing modules that can be randomly packed into the reactor or large modular blocks that can be stacked inside the reactor column. These matrices must be made of materials that are known to be non-reactive and non-leachable and non-biodegradable and be lightweight with high specific surface area and high porosity.

5.15 Specific Surface Area: The amount of surface area (e.g. square feet) provided by a unit volume (e.g. one cubic foot) of packing material.

5.16 Porosity: The extent of open space provided by the biological denitrification reactor packing material; generally computed as the volume of voids per unit volume of packing material.

5.17 Post-denitrification Treatment: Refers to all treatment methods that are required to bring biologically-denitrified water to drinking water quality and likely to include filtration and disinfection.

6.0 TASK 1: CHARACTERIZATION OF FEED WATER

6.1 Introduction

This task involves a complete characterization of the raw water being fed to the treatment system. The information is required to determine the suitability of the water source as a feed water for verification testing, and to document parameters which may be important in predicting the treatability of the water source and treatment efficiency of the treatment process.

6.2 Objectives

The objectives of this task are as follows:

- Obtain a complete physical, chemical, and biological characterization of the source water or feed water that will be treated.
- Determine the degree of nitrate removal needed and the amounts of the organic carbon source and other chemicals required to carry out the denitrification process.

- Identify potential process contaminants (foulants) such as sulfates, bacterial solids, etc., that might affect the treatment process, and to determine potential and degree of feed water pretreatment, if any, that may be needed during system operation.

- Verify that the water, as sampled, is representative of the source water based on historical data (where available).

6.3 Work Plan

This Verification Testing Plan is based on the assumption that biological nitrate removal will be predominately applied to groundwater which is not subject to significant seasonal changes in water quality or temperature. Water sources with significant variability in nitrate contamination, including surface waters, require a significantly different approach to address seasonal variations in water quality. With the exception of "effluent" streams that receive a significant component of their base flow from nitrate-contaminated groundwater sources, surface water supplies typically have not historically exhibited nitrate contamination that would require treatment.

In cases where the feed water quality is known to vary seasonally, sufficient information shall be obtained to illustrate the variations that are expected to occur in the parameters that will be measured during Verification Testing for a period of time long enough to demonstrate such variability. This information shall be compiled and provided to NSF, so NSF and the FTO can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. The initial characterization is important to the success of the testing programs, as failure to adequately characterize the feed water (source water) could result in testing at a later site deemed inappropriate. Therefore, the initial characterization is important to the success of the testing program.

A brief description of the aquifer system that provides the feed water shall be provided in the PSTP to aid in interpretation of feed water characterization results. In addition to water quality parameters, this description should include aquifer hydrogeologic characteristics that may influence the groundwater quality. Furthermore, a brief description of watershed(s) hydrologic characteristics that may have an influence on the aquifer water quality should also be provided. The watershed description should include a statement of the approximate size of the watershed, a description of its soils (i.e. clays, silts, sand, etc.) and their hydrogeologic characteristics as well as a description of it topography (i.e. flat, gently rolling, hilly, mountainous, etc.). A description of the kinds of human activities that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality should also be provided. The nature of the water source, such as stream, river, lake, or man-made reservoir, should be described as well.

Most water sources will not have pre-existing water quality data of sufficient detail to allow an evaluation of the proper application of biological denitrification. Completion of this task involves the following:

- Analysis of grab samples for a detailed water quality analysis. The parameters evaluated shall allow for the calculation of a complete cation/anion balance, in addition to general physical, chemical and biological measurements and limited organic analysis.

- A review of selected historical water quality data, where available. This should allow for the determination of trends in key water quality parameters such as nitrate, sulfate, alkalinity and

total dissolved solids (TDS) (or conductivity), as well as allowing for the verification that the water quality measured by the grab samples is representative of recent historical data.

- Calculation of the amounts of nitrates to be removed to meet existing drinking water quality standards as well as the amounts of organic carbon needed to satisfy the stoichiometric needs of denitrifying microorganism.

- Calculation of the buffering capacity of the feed water and the need to control pH. Assessment of the viability of the biological denitrification process as well as other potential interferences that may lead to biofouling. This includes estimating the concentrations of the following salts and species in the feed water stream:

    - carbonate/bicarbonate,
    - total alkalinity,
    - sulfate,
    - phosphates, and
    - iron and manganese.

The FTO shall include in the PSTP guidelines for maximum concentrations for each of the above salts during BD system operation, assuming the use of appropriate water pretreatment and conditioning chemicals, when needed.

6.4 Analytical Schedule

Parameters required for a complete evaluation of source water quality are presented in Table 1. This table identifies all required parameters for evaluation in the field or in the laboratory by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA. In order to ensure that the source water supply is of consistent quality, it is recommended that the feed water be re-evaluated periodically (monthly basis is recommended) according to Table 1 during ETV testing. Parameters in Table 1 that are found to be constant after repeated testing over time can be removed from periodic testing. Table 1 also identifies the recommended Standard Methods (APHA, 1992) or U.S. EPA-approved procedures.

Parameters to be analyzed from grab samples shall be taken in duplicates, as a minimum, or more, at least one week apart. Potential sources of historical data include the United States Geological Survey (USGS), US Environmental Protection Agency, and state and local approved laboratories.

Manufacturers and suppliers intending to have their equipment verified for uses other than biological nitrate removal may wish to characterize the source water in terms of additional parameters besides those identified in Table 1.

Table 1. Feed Water Characterization Parameters

Parameter	Analysis Options			*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
	Field	On-Line	Lab		
General Water Quality					
pH	X	X		4500-H^+ B	150.1 / 150.2
Total alkalinity			X	2320 B	
Total Hardness			X	2340 C	
Calcium Hardness			X	3500-Ca D	
Temperature	X	X		2550 B	
Conductivity	X			2510	120.1
Total Dissolved Solids			X	2540 C	
Total Suspended Solids			X	2540 D	
Turbidity	X	X		2130 B / Method 2	180.1
Color			X	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Taste and Odor[3]			X	2150-2160	
Inorganic Water Quality					
Sodium			X	3111 B	200.7
Potassium			X		200.7
Ammonia, NH_4			X		350.3
Strontium			X		200.7
Barium			X	3111 D / 3113 B / 3120 B	200.7 / 200.8
Iron			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Oxygen, Dissolved	X			4500-O	
Manganese			X	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Carbonate, CO_3			X	Calculation	
Bicarbonate, HCO_3			X	Calculation	
Sulfate, SO4	X		X	4110 B / 4500-$SO4^=$ C, D, F	300.0 / 375.2
Chloride	X		X	4110 B / 4500-Cl^- D	300.0
Nitrate, NO_3	X		X	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Nitrite, NO_2	X		X	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Fluoride			X	4110 B / 4500-F^- B, C, D, E	300.0
Carbon Dioxide, CO_2			X	6211 M	
Hydrogen Sulfide, H_2S	X				376.1/2
Organic Water Quality					
Total organic carbon			X	5310 C	
Electron Donor[4]	X		X	TBD	
UV_{254} absorbance			X	5910 B	
AOC/BDOC			X	9217A/5310	
Microbiological					
Total coliform			X	9221, 9222, 9223	
Heterotrophic Plate Count			X	9215 B	

1) Standard Methods Source: APHA (1999).

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water (1996).

3) Taste and Odor measurements are optional.

4) Residual electron donor (i.e. carbon source) concentration; TBD = To be determined by the FTO. See Section 5.7, FTO must identify Standard Method for their carbon source of interest (i.e. alcohols, organic acids, or sugars). Note that the choice of electron donor could interfere with ion chromatography-based measurements.

6.5 Evaluation Criteria

Feed water quality shall be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment with respect to nitrate concentration, but should not be beyond the range of water quality parameters suitable for treatment for the equipment in question.

The detailed chemical analysis should lead to a detailed determination of chemical doses required to support and maintain the biological process including organic carbon, pH control, dissolved oxygen control, and other process maintenance measures. Furthermore, the detailed water quality analysis results should allow for the determination of feed water constituents that may cause interferences, or potential biofouling, during biological denitrification. The analysis should lead to the proper selection of the chemical pretreatment options (i.e. chemical addition), if needed, to control and minimize such interferences.

If the feed water does not contain the level of nitrate concentration required to verify the manufacturer's removal objectives, nitrate spiking may be employed. The nitrate spiking procedure must be a peer-reviewed and published procedure and it must be reviewed by NSF and the EPA prior to implementation. Manufacturers and FTOs should also be aware that there are professional opinions that are opposed to nitrate spiking for verification testing.

7.0 TASK 2: BD START-UP AND INITIAL PERFORMANCE

7.1 Introduction

The purpose of this task is to verify that the BD system, when tested in accordance with Manufacturer-selected operating conditions using the selected source water, can reach and maintain performance as defined by:

- Productivity (product flow)
- Nitrate concentration (and other salts, if applicable)
- Concentrations of residual dissolved and suspended organic solids in the BD effluent
- Degree of post-denitrification treatment required to elevate the water quality to drinking water standards.

Another purpose of this task is to demonstrate that changes in the level of these performance characteristics caused by biofouling or other interactions between the BD system and the feed water can be adequately managed through conventional process modifications, chemical addition, or through conventional post-denitrification treatment.

The start-up of biological treatment systems requires the selection and enrichment of a non-pathogenic biological culture capable of efficiently and selectively removing nitrate from water. This biological culture must be accumulated within the reactor packing material to provide constant and steady-state nitrate removal. The accumulation of such solids will require careful operation during the start-up period to avoid the sudden washout of biological solids due to hydraulic transient conditions. Furthermore, the biological

system will require careful monitoring to assure that minimum trace elements and buffer are provided and that excess nitrate loading is avoided. Additionally, suitable environmental conditions including moderate temperature and pH levels must be maintained. Although biological denitrification can be carried out at all normal temperatures above freezing, the maintenance of moderate temperature (i.e. 50 – 80 F) is conducive to desirable denitrification rates.

Beyond start-up, the BD system must be operated under steady-state operating conditions as specified by the FTO. While product flow is maintained, measures shall be taken to optimize (i.e. reduce) the concentrations of residual soluble and suspended organic materials (including bacterial numbers) in the denitrified effluent to minimize post-denitrification treatment needs.

As the biomass inventory in the system increases to the point where it is measurably impacting the BD system effluent quality, this biomass inventory will need to be managed as described in Task 4 to reduce the concentrations of residual suspended organic matter in the system effluent.

In the event that biofouling is judged to be excessive and unacceptable, the Manufacturer shall propose revised operating conditions to reduce such fouling. The effect of corrective measures on water productivity and BD effluent quality water shall then be determined through additional testing.

Prior to the start of the Verification Testing Program, the operational conditions to be verified shall be specified by the FTO in terms of an average water production rate (gallons per day [gpd]), nitrate removal efficiency, and organic carbon use rates.

7.2 Objectives

The objectives of this task are to document the following:

- Conditions for the BD system start-up and long-term operation.
- Performance of the BD system when operated under variable loading conditions.
- Effluent quality achieved by the BD system.
- Chemicals use and their impact on the treated water supply

7.3 Work Plan

7.3.1 Operational Conditions and Start-up

The PSTP shall specify information concerning the design and operation of the BD treatment system being evaluated in the following categories: 1) system design criteria; 2) operating conditions; 3) written procedures for operation and maintenance; and 4) maintenance criteria. To achieve and maintain successful long-term biological denitrification, numerous considerations need to be kept in mind during the various phases of reactor selection, design, start-up and operation. These considerations are discussed briefly below:

1. **Reactor selection and configuration:** To provide an acceptable level of system reliability, care must be taken during the BD system reactor selection and configuration. For example, the use of single-stage systems can be acceptable provided that more than one reactor is provided to meet minimum reliability requirements. When economically justifiable,

two-stage systems can provide a crucial degree of reliability to ensure long-term operation and maintenance. This level of reliability can yet be increased by utilizing multiple trains of two stage systems. Work by numerous researchers has demonstrated that two-stage reversible-flow reactor configurations are extremely efficient in providing increased levels of operational reliability beyond that provided by once-through two-stage systems (Siddique, and Young, 1995; Dahab and Kalagiri, 1996; Dahab and Woodbury, 1998). The PSTP should justify the use of single-stage systems, or single-stage systems with recycle over two-stage systems based on process as well as economic considerations.

Furthermore, the type of packing media should be specified based on expected hydraulic flow regime, packing media porosity, specific surface area and other pertinent considerations including materials of construction of packing media, density and chemical characteristics. Packing materials that are known to be non-reactive, non-leachable and non-biodegradable should be selected.

2. **Operational Controls:** The PSTP shall delineate the BD process and its controls based on kinetic as well as process hydraulic considerations, reactor dimensions, flow rates, influent nitrate concentrations, and proposed detention times. The PSTP shall also delineate steps to optimize the BD system by consideration of split (partial) treatment to provide for sufficient, yet flexible, denitrification capacity to meet the nitrate and nitrite standards while minimizing the total flow requiring actual biological treatment (i.e. treating a portion of the flow and blending it with the remaining untreated portion).

3. **Reactor Seeding and Seed Selection:** The PSTP shall specify how the BD system is to be seeded with denitrifying culture and how such non-pathogenic culture is to be obtained. There are many species of non-pathogenic bacteria that are capable of denitrification which are found in soils and natural waters. Such bacteria can be harvested and enriched for inoculation of the BD reactors. Many such bacterial cultures also can be obtained from commercial suppliers.

4. **Carbon Source Selection:** The most efficient species of denitrifying bacteria are typically facultative heterotrophs that require organic carbonaceous material be added as a source of energy for growth and multiplication. The PSTP shall specify the type of carbon to be provided for metering into the feed water. Typically, simple organic carbon sources are the most efficient from the standpoint of minimizing the amount of biosolids production as well as being fully utilized during the biodenitrification reaction. Additionally, the organic carbon source selection is typically based on cost as well as public health considerations. For example, while being a fully biodegradable simple organic molecule, methyl alcohol may not be acceptable because of potential toxicity implications. Based on economic and kinetic considerations, ethyl alcohol is an ideal denitrification carbon source, but it may, or may not be desirable from the standpoint of public acceptance.

5. **Dissolved Oxygen (DO) Control:** Dissolved Oxygen (DO) control is important to maintain anoxic conditions for optimum denitrification in the reactor system. The PSTP shall specify the methods by which dissolved oxygen would be reduced, if present in significant concentrations. DO can be removed by the addition of a reducing agent (e.g. sodium sulfite) or by relying on aerobic carbonaceous bacterial reaction to consume the DO in the feed water.

The latter method implies that additional organic carbon would need to be provided to satisfy the dissolved oxygen demand. Subsequent to biological denitrification, it may be desirable to restore the DO concentration in the treated water. This measure generally should contribute to the improvement of the chemical and aesthetic quality of the treated water as DO will be helpful in the oxidation and removal of residual dissolved and suspended organics in the treated water as well as help reduce potential malodorous conditions. The PSTP should address this important issue by examining the need for post-denitrification oxygen addition.

6. **Product Gas Removal:** The PSTP shall indicate how gases produced during denitrification will be exhausted from the reactor system. These gases are typically made of nitrogen gas and carbon dioxide and thus, need to be properly vented to the atmosphere.

7. **Control of pH:** The PSTP shall specify methods to monitor and control pH levels in the treated water supply, if necessary. Typically, biological denitrification will result in increasing the water pH. Depending on the influent nitrate concentration in the feed water and the available buffering capacity of the water, pH control might be necessary. Fortunately, most groundwater supplies will contain sufficient alkalinity to counteract this phenomenon, assuming that nitrate contamination is moderate.

8. **Excess Biomass Production:** During biological denitrification, a certain amount of biomass is produced and accumulated in the reactor as either attached biofilm or suspended biomass floc, biomass granules, or similar agglomerations. The PSTP shall specify methods of biosolids control including wasting frequency and reactor backwash procedures, if necessary.

7.3.2 Response to Transient Loading Conditions

The ability of the BD System to respond to changes in loading conditions shall be determined after steady state operation is reached and maintained for a period of about 3-4 weeks. Measures shall be taken to challenge the system's ability to respond to transient increases in nitrate concentration and/or hydraulic loading rates. This can be accomplished by altering the loading rates to the BD system for a duration equal to at least 3-4 hydraulic detention times. If the nitrate concentration in the water supply is not sufficiently variable, then this can be accomplished by gradually increasing the hydraulic loading rate by at least 50 percent (ideally in increments spanning about 1-2 hydraulic detention times). The BD reactor system performance shall then be monitored throughout the transient test period. If the water supply nitrate concentration is known to be variable, then the system can be operated at a constant flow rate while observing and documenting the reactor performance for a period of time of sufficient length such that a 40-50% change in nitrate concentration, if possible, is observed.

7.3.3 Response to Extended Periods of Shutdown

The ability of the BD System to respond to periods of dormancy, or shutdown, shall be determined after steady state operation is reached and maintained for a period of about 3-4 weeks. The ability of the system to respond to extended shutdown can be accomplished by gradually turning the flow to the system off, keeping it off for a period of 5-6 days, and then gradually restarting the system. The BD reactor system performance shall then be monitored throughout the restart-up period and until normal performance is re-established.

7.3.4 Product Effluent Water Quality

The key parameters in measuring the quality of the biologically treated water are the effluent nitrate concentration and the concentration of other substances, organic and inorganic, that can result from the biological treatment process. These byproducts are generally considered to be foulants and thus must be reduced to acceptable levels. The PSTP shall address this issue by providing detailed product water analysis and specifying steps to reduce, or remove foulants resulting from water treatment. These issues are further detailed in Task 3.

7.3.5 Chemical Use

Successful biological denitrification requires the use of chemicals that can facilitate the vitality of the biological culture that removes nitrate from water as well as re-condition the treated water quality to meet prevailing drinking water quality. Typical chemical additives are listed in Table 2 below. The PSTP must address the need for chemical addition either as pre-denitrification or as post-denitrification additives and specify chemical addition rates, metering and dosing systems and provide for proper storage and handling facilities for these substances.

Table 2. Typical Chemical Additives Required for Biological Denitrification.

Chemical	Purpose	Use/Addition
Organic Carbon sources including Ethanol, Acetic Acid, Acetate, and Others	Organic Carbon Source	Pre-denitrification
Hydrochloric acid	pH control	Denitrification
Bicarbonate	pH control	Denitrification
Phosphate	P-source	Pre-denitrification
Phosphoric Acid	P-Source	Pre-denitrification
Sulfite, Sodium	DO Control	Pre-denitrification
Oxygen	DO Control, Oxidant	Post-denitrification

7.3.6 Power Use

In an attempt to calculate power costs for operation of the system, power usage shall be measured by meter readings or quantified by the following measurements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor.

7.3.7 Operator Hours

In an attempt to calculate labor hour costs for operation of the system, operator hours shall be recorded during the verification testing.

7.4 Analytical Schedule

During Verification Testing of the BD system equipment, the feed water and treated water quality shall be characterized by measurement of the "Field" water quality parameters listed previously in Table 1. These data are to be collected and analyzed to enhance the usefulness of the Verification Testing data.

The sampling schedule and sampling frequency shall conform to sampling schedule and sampling frequency defined in Task 3 (Product and Residuals Management) and Table 3.

7.5 Evaluation Criteria

Where applicable, the data developed from this task should be compared to statements of equipment performance objectives. If no relevant statement of performance capability exists, results of operating and performance data should be tabulated for inclusion in the verification report.

8.0 TASK 3: PRODUCT AND RESIDUALS MANAGEMENT

8.1 Introduction

Under normal conditions, BD involves the production of minor amounts of wastewater; most of which is associated with the flushing and periodic backwash of the denitrification reactors. This task involves a characterization of product and waste water quality during the system operation described in Task 2. Product water analysis shall serve to document that the treatment system meets the nitrate removal performance criteria for which the manufacturer is seeking verification. Additional water quality information is required to identify performance of the treatment system relative to any potential fouling identified during the raw water characterization performed in Task 1.

The quality and quantity of wastewater produced by the BD treatment system is an important consideration in determining the appropriate methods of management and disposal of this wastewater. The cost of wastewater disposal typically is not a large component of the total system cost, but it can be significant depending on the type of disposal option selected, particularly for those not utilizing a direct discharge to an existing wastewater treatment system.

8.2 Objectives

The objectives of this task are as follows:

- Assess the ability of the biological treatment system equipment to meet the water quality goals specified by the Manufacturer.
- Assess the amount and concentrations of any potential foulants which may interfere with the long-term operation of the treatment system. Examples include excessive sulfate concentrations that can lead to the production of sulfide and other dissolved and suspended solids that can interfere with the biological treatment process.
- Characterize the volume and concentration of the wastewater produced by the process.

8.3 Work Plan

Water quality data shall be collected for the BD treatment system feed water and product during the BD test as outlined in Task 2. As a minimum, the required sampling schedule identified in Table 3 shall be observed by the FTO on behalf of the Manufacturer. Water quality goals and target removal goals for the BD equipment shall be clearly delineated in the PSTP.

When necessary, excess solids must be removed from the reactor system to maintain a suitable and adequate solids inventory in the reactors. When solids removal is implemented, characterization of the amount and quality of wastewater that needs to be removed must be completed. The biological solids (biosolids) to be removed from these reactors are non-toxic, but they must be handled and managed in an approved manner in consultation with the requisite regulatory agencies. The most appropriate method of disposal might be the discharge of these solids and wastewater to a nearby municipal biological wastewater treatment system with adequate capacity to handle the solids load. Otherwise, solids concentration (i.e. thickening and/or dewatering) might be needed before disposal of these solids to land as a soil conditioner. Additional disposal methods might be available. The PSTP must specify, based on local conditions and regulations, the method(s) of solids handling and ultimate disposal.

8.3.1 Sampling Schedule:

The sampling schedule outlined in Table 3 applies to the biological denitrification system raw feed water and treated water streams. Some parameters identified in Table 3, including nitrate and nitrite, should be analyzed on a continuous basis, or on a multiple daily measurement basis, as appropriate. However, when continuous analysis is not possible, these parameters shall be analyzed at least once every four to six hours.

The FTO shall identify the treated water quality objectives to be achieved in the statement of performance objectives of the equipment to be evaluated in the Verification Testing Program. The statement of performance objectives prepared by the FTO shall indicate the range of water quality under which the equipment can be challenged while successfully treating the feed water.

Many of the water quality parameters described in this task shall be measured on-site by the FTO or by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA.

The methods to be used for measurement of water quality parameters in the field are summarized in Table 3. The analytical methods utilized in this study for on-site monitoring of influent and product water qualities are described in Standard Methods (APHA, 1992) and/or the U.S. EPA. Methods and are governed by their respective QA/QC measures. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA, water samples shall be collected in appropriate containers (using recommended sample preservatives techniques, as applicable) prepared, or otherwise approved, by the laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with recommended procedures and holding times, as specified by the analytical lab.

TABLE 3. BD SYSTEM SAMPLING SCHEDULE DURING ETV TESTING

Parameter	Sampling Frequency[1]	Analysis Options	*Standard Methods*[2] number or Other Method Reference	EPA Method[3]
Nitrate, NO^3	Multiple Daily (or continuous)	Field or Lab	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
Nitrite, NO^2	Multiple Daily (or continuous)	Field or Lab	4110 B / 4500-$NO3^-$ D, F	300.0 / 353.2
pH	Multiple Daily (or continuous)	Field or On-line	4500-H^+ B	150.1 / 150.2
Temperature	Daily	Field or On-line	2550 B	
Dissolved Oxygen	Multiple Daily (or continuous)	Field	4500-O	
Turbidity	Multiple Daily (or continuous)	Field or On-line	2130 B Method 2	180.1
TDS	Weekly	Lab	2540 C	
Conductivity	Weekly	Field	2510	
Sulfate, SO4	Daily	Field or Lab	4110 B / 4500-$SO4^=$ C, D, F	300.0 / 375.2
Sulfide	Daily	Lab	4500-$S^=$ F, D	
TSS	Daily	Lab	2540 D	
VSS	Daily	Lab	2540 E	
TOC	Daily	Lab	5310 C	
DOC	Daily	Lab	5310 C	
Carbon source (electron donor)	Daily	Field or Lab	TBD	
Total Coliform	Weekly	Lab	9215 B / 9221 / 9222 / 9223	
E. Coli	Weekly	Lab	9221 / 9222 / 9223 (Colilert)	
UV Absorbance (254 nm)	Daily	Lab	5910 B	
Alkalinity	Daily	Lab	2320 B	
Total Hardness	Weekly	Lab	2340 C	
Color	Weekly	Lab	2120 B (Hach Company modif. of SM 2120 measured in spectrophotometer at 455 nm)	
Taste and odor[4]	Weekly	Lab	2150-2160	
Iron and Manganese	Weekly	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Chloride	Weekly	Field or Lab	4110 B / 4500-Cl^- D	300.0

1 Grab samples unless continuous sampling.
2 Standard Methods Source: APHA (1999).
3EPA Methods Source: EPA Office of Ground Water and Drinking Water (1996).
4Taste and Odor measurements are optional.

8.4 Analytical Schedule

The minimum sampling frequency for the required Task 3 water quality parameters is presented in Table 3. At the discretion of the FTO, the water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling. As indicated

earlier in Section 6.4, periodic (e.g. monthly) extensive re-evaluation of the feed water supply is recommended using all parameters listed in Table 1 to ensure that the feed water is of consistent quality. Such extensive evaluation is prudent to guard against possible sudden changes in feed water quality.

Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP. However, to the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

8.5 Evaluation Criteria

- **Nitrate Removal**

  The primary BD system evaluation criterion is the nitrate removal capacity expressed as the amount of nitrate removed per unit reactor volume per unit time (e.g. lb NO_3-N/ft^3-hr) claimed by the manufacturer for the application being verified.

  Provide a graph showing the BD influent and product water nitrate concentrations as a function of elapsed operating time.

- **Fouling**

  As indicated earlier, depending on raw water quality, biological denitrification can result in additional byproducts of nuisance and/or fouling potential. Detail must be paid to careful operation to minimize the occurrence and production of such materials. Optimizing the BD reactor operating conditions should result in minimization of these substances in the reactor effluent.

  Provide graphs showing the levels of contaminants in the raw water and treated water supplies as a function of elapsed time including dissolved and suspended solids, residual organic carbon source concentrations, and hydrogen sulfide.

9.0 TASK 4: PROCESS AND EQUIPMENT MAINTENANCE

9.1 Introduction

Under this task, the FTO shall demonstrate that adequate steps are being taken to insure the continued maintenance of both the biological denitrification process as well as the BD process equipment. The process maintenance schedule shall delineate steps to be taken to preserve process stability while maximizing the nitrate removal rate and minimizing the extent of potential fouling of the product water quality. Process maintenance must involve at minimum:

- Target nitrate removal rates are met while maintaining potential nitrite concentration at desired levels,
- Production of minimal concentrations of residual organic carbon,
- Production of minimal concentrations of suspended and dissolved organic solids of cellular or extracellular origins, and

- Minimization of the production of substances that can cause, or contribute taste, color, and/or odor in the treated water.

The process equipment schedule shall outline steps to be taken to insure the continued optimum functioning of all process equipment including chemical dosing, process control and monitoring equipment.

9.2 Objectives

The objectives of this task are as follows:

- Outline steps to evaluate and maintain the continued effectiveness of the biological process in removing nitrate while reducing the potential production of fouling substances.
- Confirm that Manufacturer-recommended equipment management schedules (Manufacturer Operations and Maintenance [O&M] Manual) are sufficient to maintain the continued functional integrity of all process control and monitoring, and that procedures and methods to restore the integrity of such equipment upon malfunction, are current.

9.3 Work Plan

9.3.1 Process Maintenance

The FTO shall ascertain that:

1. Organic carbon dosing equipment is set to correspond to stoichiometric limits dictated by the influent feed water nitrate concentration and the influent water DO concentration.

2. Reactor environmental conditions are maintained at optimal levels with respect to pH, temperature, and adequate supply of essential trace elements and nutrients.

3. The attached and suspended solids inventories in the reactor system are monitored on a regular and continuous basis and that excess biological solids are removed by draining or backwashing, or both. A reactor backwash procedure based on the type(s) of biomass support matrix characteristics (packing density, porosity, and specific surface area) should be maintained. When possible, the frequency of backwash should be established to allow for better process automation.

9.3.2 Equipment Maintenance

Regular schedule and O&M manuals for equipment testing, calibration mechanical maintenance and replacement and/or repair are required. The following are recommended criteria for evaluation of O&M manuals for BD treatment systems.

9.3.2.1 Operation. Provide clear and concise recommendations for procedures related to proper operation of the BD treatment system and equipment. Include as a minimum, information on the following:

- Startup

  Initial startup of system including reactor seeding
  Establishment of steady state operation
  Restart and possible reseeding of the reactor system after prolonged shutdown

- Shutdown and biomass inventory management

  Short term shut down (one day or less)
  Intermediate term (one day to one week)
  Long term (more than one week)

- Backwash Procedures

  Backwash cycle details including duration
  Backwash frequency

- Chemical Feed Systems

  All chemicals with anticipated use
  Dosing rates
  Automation of chemical control system (e.g., pH, control of carbon source feed)

- Tolerance of the system to operating conditions

  Feed water temperature
  pH
  Oxidants (e.g., dissolved oxygen, chlorine, etc.)
  Maximum feed pressure and maximum allowable differential pressure across each stage of the reactor system

- Adjustment to operating parameters

  Influent water flow rates
  Influent water nitrate and DO concentrations

9.3.2.2 Maintenance. Provide clear and concise procedures for performing maintenance on the system and its components.

- Instructions for installing or replacing system control and process monitoring equipment and components.
- Recommended or required maintenance schedules for each piece of equipment.
- A list of spare parts to be kept on hand.

9.3.2.3 Troubleshooting. Provide clear and concise procedures for troubleshooting.

- Provide an explicit list of alarm conditions that the system must respond to:

  Pressure
  pH
  Pump Failure
  Chemical feed low tank level

- Indicate which alarm conditions will cause automatic system shutdown and provide instructions for clearing each condition.

- Provide detailed procedures for verifying integrity of the reactor system, back-flow prevention, all flow control and check valves, etc. on a vessel-by-vessel basis.

10.0 TASK 5: DATA REDUCTION AND PRESENTATION

10.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software, manual recording methods, or both, for recording operational parameters of the BD equipment on a daily basis.

10.2 Objectives

The objectives of this task are as follows:

- Establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for verification purposes.

- Develop a statistical analysis of the data, as described in "EPA/NSF ETV Protocol For Equipment Verification Testing For Removal Of Nitrate: Requirements For All Studies" (Chapter 1).

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into a spreadsheet software as a comma delimited file. These specific database parcels should be identified based upon discrete time spans and monitoring parameters. In spreadsheet format, the data should be manipulated into a convenient framework to allow analysis of equipment operation. Backup of the computer databases should be performed on a daily basis, if possible.

In the case when a SCADA system is not available, field testing operators shall record all data and calculations by hand in laboratory notebooks (daily measurements shall be recorded on specially-prepared data log sheets, as appropriate). The laboratory notebook should provide carbon copies of each page.

The original notebooks shall be stored on-site; the carbon copy sheets should be forwarded to the project engineer of the FTO at least once per week. This protocol should not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the BD equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry should be conducted on-site by the designated field testing operators. All recorded calculations should also be checked at this time. Following data entry, the spreadsheet should be printed out and the printout is checked against the handwritten data sheet. Any corrections shall be noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet should be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each test run) shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to analytical laboratories that are certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

11.1 Introduction

Quality assurance and quality control of the operation of the BD equipment and the measured water quality parameters shall be maintained during the verification testing program.

11.2 Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it would be possible to verify exact conditions at the time of testing.

11.3 Work Plan

Equipment flow rates and associated signals should be verified and verification recorded on a routine basis. A routine daily walk through during operation shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate into a flow stream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flow meters, etc. shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being

recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

11.3.1 Daily QA/QC Verifications

- Chemical feed pump flow rates (verified volumetrically over a specific time period).
- On-line turbidimeter flow rates (verified volumetrically, if employed).
- On-line turbidimeter readings checked against a properly calibrated bench model, if employed.

11.3.2 Weekly QA/QC Verifications

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- Recalibration of on-line pH meters and/or conductivity meters, if used.

11.3.3 QA/QC Verifications Performed Before Each Test Period

- On-line turbidimeters (clean out reservoirs and recalibrate, if employed).
- Differential pressure transmitters, if used (verify gauge readings and electrical signal using a pressure meter).
- Tubing (verify good condition of all tubing and connections, replace if necessary).

11.3.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw feed water and product water quality are described in the sections below. Use of either bench-top or on-line field analytical equipment should be acceptable for the verification testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

11.3.4.1 pH. Analyses for pH shall be performed according to Standard Method 4500-H. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual.

11.3.4.2 Turbidity. During each verification testing period, the in-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument shall serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of verification testing and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples shall consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

In-line Turbidimeters. In-line turbidimeters shall be used for measurement of turbidity in the filtrate water during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments, the readings should be comparable. Should the comparison suggest inaccurate readings, then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

11.3.5 Chemical and Biological Samples Shipped Off-Site for Analysis

TOC and UV absorbance samples shall be collected in glass bottles supplied by the laboratory (certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA) and shipped at 4°C to the analytical laboratory within 8 hours of sampling. The TOC and ultraviolet (UV) absorbance samples shall be collected and preserved in accordance with Standard Method 5010B

Inorganic chemical samples, including alkalinity, hardness, iron, and manganese, shall be collected and preserved in accordance with Standard Method 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples should be refrigerated at approximately 2 to 8°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8°C. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e. NSF), or the U.S. EPA within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of analysis.

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied (or approved) by the qualified laboratory and shipped with an internal

cooler temperature of approximately 2 to 8°C to the analytical laboratory. Samples shall be processed for analysis by the qualified laboratory within 24 hours of collection. TC densities are reported as most probable number per 100 milliliters (MPN/100 mL) and HPC densities are reported as colony forming units per milliliter (cfu/mL).

12.0 REFERENCES

American Public Health Association, (APHA), Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1999, APHA, Washington, DC.

Dahab, M.F. and W.L. Woodbury, 1998, "Biological Treatment Options for Nitrate Removal From Drinking Water," *Proceedings of the AWWA Inorganic Contaminants Workshop*, San Antonio, TX, Feb 22-24.

Dahab, M.F. and J. Kalagiri, 1996, Nitrate removal from water using cyclically operated fixed-film bio-denitrification reactors, *Water Science and Technology*, 34, 1-2, 331-338.

Dahab, M.F., G.A. Guter, and F. Rogalla, 1991, Experience with nitrate treatment in the United States and Europe, Proceedings, Annual Conference, American Water Works Association, Philadelphia, PA, June 23-27.

Gayle, B. P., G. D. Boardman J. H. Sherrard and R. E. Benoit, 1989, Biological denitrification of water, *Journal of Environmental Engineering*, 115, 5.

Rogalla, F., G. de Larminat, J. Coutelle, and H. Godart, 1990, Experience with nitrate removal methods from drinking water, in: "*Nitrate Contamination: Exposure, Consequences and Control*", NATO ARW Series G, Vol. 30, I. Bogardi and R.D. Kuzelka, Editors, Springer-Verlag Publishers.

Siddique, M.A. and J.C. Young, 1995, Denitrification using a two-stage cyclic process. Proceedings of the 68th Annual Conference of the Water Environment Federation, Miami, FL, Oct. 21-25.

U.S. Environmental Protection Agency, 1996, ICR Manual for Bench and Pilot-Scale Treatment Studies, Office of Ground Water and Drinking Water, Cincinnati, Ohio.